Energy Consumption Analysis and Energy Conservation Evaluation of a Commercial Building in Shanghai

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Abstract: The paper presents a model of a commercial building in Shanghai with energy simulation software, and after calibration, the energy consumption of this building is calculated. On the basis of the simulation and calculation, a series of energy saving measures are suggested and their effects are evaluated. The paper verifies the application of computer simulation in building energy analysis and energy saving evaluation.

Key words: commercial building; energy consumption analysis; energy conservation evaluation

1. INTRODUCTION

The energy consumptions of large scale commercial buildings are huge, while most facility management departments in these buildings do not have efficient measurement methods and devices to get the performance and efficiency of energy using equipments as well as the energy usage by them. Therefore it is very hard for them to take relevant energy conservation measures (ECMs). Even though some ECMs were taken, it is always difficult to evaluate the energy conservation benefits. This paper employs calibrated simulation technique to simulate and analyze the energy consumption of a commercial building in Shanghai. Six ECMs were evaluated based on the calibrated model and energy analysis of this building.

2. BUILDING'S GENERAL INFORMATION

This mansion is a high standard commercial building, which provides the service of finance, business, restaurant and amusement, etc. It has been used for more than 10 years. This building has a total area of 67000m2, 40 floors over ground and 1floor underground. The area with air conditioning system is 58500m2. The air conditioning system of the office area in this building is fan coil system and dedicated outdoor air system and that of the common area is constant air volume system. The building has 3 centrifugal electric chillers (900RT for 2, 400RT for 1) and 3 fuel steam boilers (4.5 MW each).

3. BUILDING ENERGY SIMULATION MODEL

This model is made by eQUEST (Quick Energy Simulation Tool), which is an hourly whole building simulation software. Its calculating core is DOE-2.2.

The inputs of the model include geometry modeling, envelope parameters, internal loads, schedules and the operating parameters of HVAC system, etc.

3.1 Building Geometrical Model

The geometrical model is based on the blue print of the mansion (Figure 1). Many unnecessary configurations were predigested to reduce the model scale and save time of calculation.

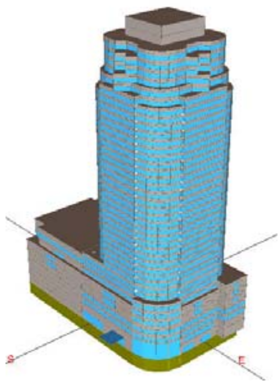

Fig.1 Building model

3.2 Building Envelope

Table 1 gives the characteristics of envelope of the building.

Tab. 1 Model envelope

Envelope	U Value(W/ m^2·K)
Exterior Wall	3.05
Interior Wall	2.28
Floor	2.27
Ground	0.47
Ceiling	2.05
Roof	2.91
Glass	6.17
	6.12

3.3 Internal Loads and Schedules

The people density, lighting load, plug load and operating schedule of the building were input according to the design information and site measurement(See Table 2).

3.4 HVAC System Zoning

Figure 2 shows the HVAC zoning in a typical floor of the model. It is a predigestion of the actual building.

3.5 HVAC System

Table 3 presents the relative parameters of HVAC system of the building.

Tab. 3 HVAC operating parameters

Operating Parameters	Model Value
HVAC Type	FCU + CAV
Heating Set Point	22±2□
Cooling Set Point	24±2□
COP	4.5
Chilled Water Temp	6□/10.5□
Boiler Efficiency	60%
Fresh Air flow rate	30m^3/p·h

4. BUILDING ENERGY SIMULATION AND MODEL CALIBRATION

4.1 Model Calculation and Calibration

In the original model, the TMY weather data of Shanghai was used to simulate the building energy.

In addition to supply heating in winter, the boilers supply steam for sauna in the building, and the energy usage of this part has no measurement. So it is difficult to use the model to simulate the fuel consumption of the building. In this paper, only electrical consumption was considered.

In figure 3, the blue curve shows the real electrical consumption of the building in 2004 and ±10% error. The red one shows the monthly electrical consumption of original model.

Tab. 2 Internal load and schedule list

Zone Type	People Density (m^2/p)	Lighting Load (W/m^2)	Plug Load (W/m^2)	Schedule
Office	18	15	15	9:00~17:30
School	3	20	25	9:00~20:30
Bank	4	15	25	8:30~21:00
Restaurant	6	40	10	11:30~22:00
Retail	5	25	10	10:00~22:00
Garage	500	5	—	—
Corridor	35	10	—	—

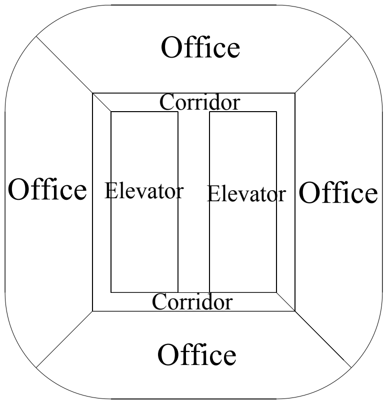

Fig.2 Typical floor HVAC zoning

The original model had some errors with actual building. Table 4 shows the value of these errors. The maximum error of monthly energy usage is 22.24%. So the model were calibrated three times:

1) Using real meteoric data of 2004 instead of TMY weather data;

2) Refining HVAC system operating schedules according to the actual schedules;

3) Refining lighting loads according to site measurement.

Figure 3 shows the monthly electrical usage of three calibrated model.

4.2 Model Evaluation

In Chinese, there are no relative standards available for the evaluation of calibrated simulation. So this paper introduces some international standards as followed.

1) ASHRAE Guideline 14-2002, Measurement of Energy and Demand Savings[4]. It was developed by ASHRAE to fill a need for a standardized set of energy(and demand)savings calculation procedures. The intent is to provide guidance on minimum acceptable levels of performance for determining energy and demand savings, using measurements, in commercial transactions.

2) IPMVP, International Performance Measurement and Verification Protocol[5]. It provides an overview of current best practice techniques available for verifying results of energy efficiency, water efficiency, and renewable energy projects. It may also be used by facility operators to assess and improve facility performance.

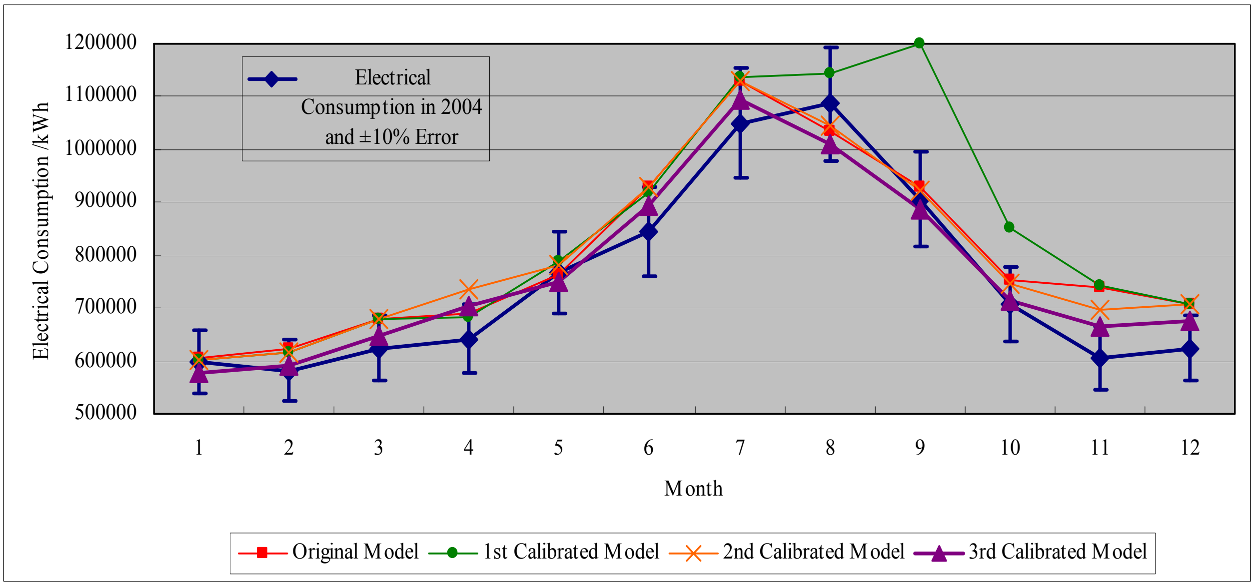

Fig.3 Simulated energy consumption compared with actual energy usage in 2004

Tab. 4 Acceptable tolerance and model errors [3]

Error Index	ASHRAE 14P	IPMVP	FEMP	Original Model Error	1st Calibrated Model Error	2nd Calibrated Model Error	3rd Calibrated Model Error
ERR_{month}	±5%	±20%	±15%	−22.24%	−32.45%	−15.2%	−10.01%
ERR_{year}	—	–	±10%	−6.76%	−11.27%	−6.71%	−2.37%
CV($RSME_{month}$)	±15%	±5%	±10%	8.65%	15.08%	8.12%	5.70%

ERR_{month}: Monthly Error

ERR_{year}: Yearly Error

CV(RMSE): the Coefficient of Variation of the Root Mean Squared Error

3) FEMP, Federal Energy Management Program[6]. The purpose of this document is to provide guidelines and methods for measuring and verifying the savings associated with federal agency performance contracts.

According to the standards above, the original model and the ones calibrated can be evaluated by ERRmonth, ERRyear and CV(RSMEmonth) (see Table 4).

From the results in Table 4, the last calibrated model has been accorded to the FEMP. The ERRmonth is bigger than the tolerance of ASHRAE 14P and the CV(RSMEmonth) is a little bigger than the tolerance of IPMVP. But the errors between the simulated results and the actual data still exist. The reasons can be:

1) The actual randomicity of the operating schedule of internal loads can not be simulated exactly in the model.

2) Since there is no building automation in the building, the HVAC system is controlled manually, which may not always operates as the schedules set in the model.

3) The detailed information of the envelope construction can not be found, which may cause error in the simulation of the heat gain through the envelope.

5. BUILDING ENERGY CONSUMPTION ANALYSIS

The energy consumption analysis of this mansion is based on the basic calibrated model.

5.1 Energy Consumption Indices

Total electrical consumption： 9,210,007 kWh/year

Total oil consumption： 9,719,002 MJ（242.2 t）/year

Electrical consumption： 157.4 kWh/ m^2·year

Oil consumption： 166.1 MJ/ m^2·year（4.14 kg/m^2）

Electrical cost： 7,395,636 RMB/year

Oil cost： 1,005,130 RMB/year

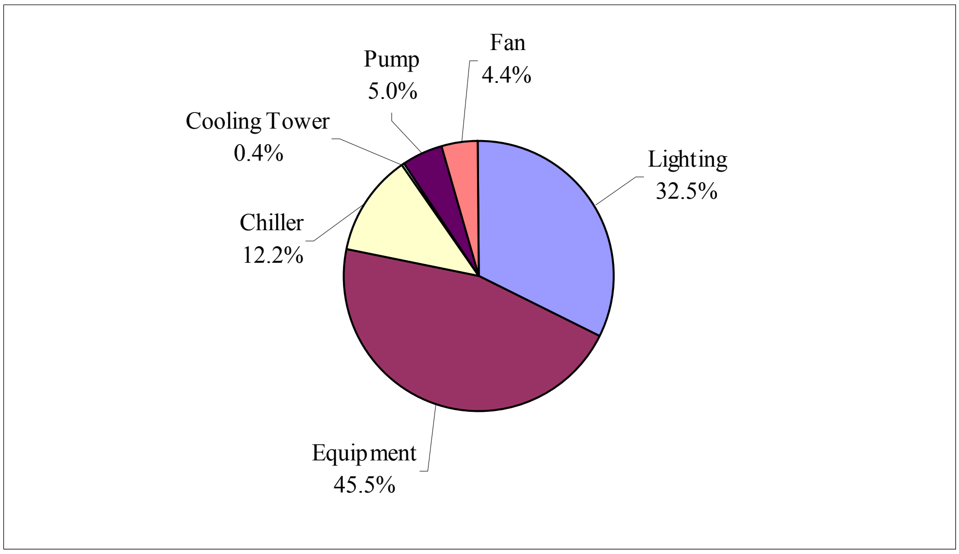

Fig.4 Electrical usage breakdown

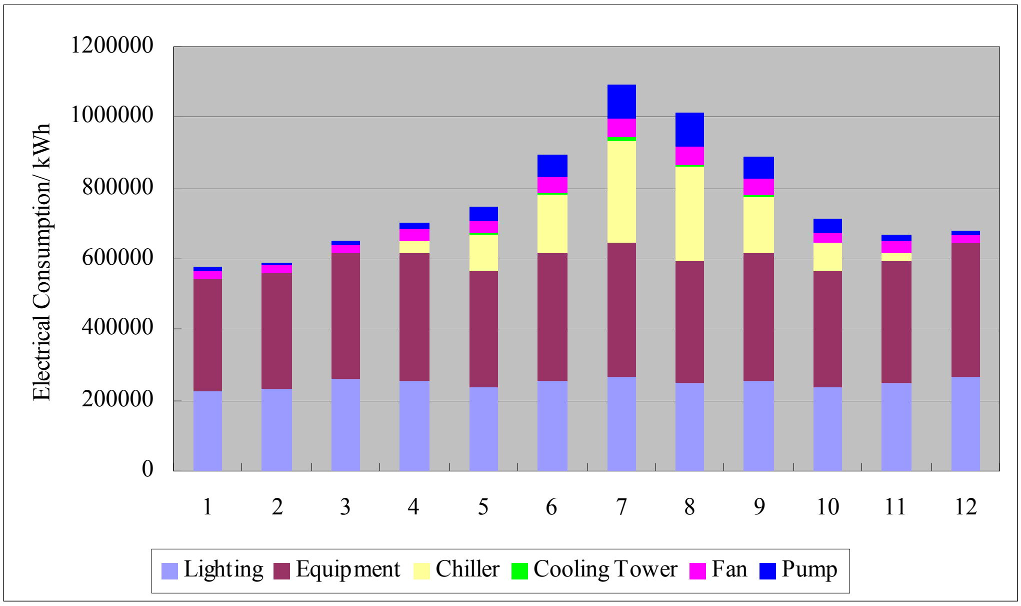

Fig.5 Monthly electrical usage

Total energy cost:	8,400,766 RMB/year
Electrical cost:	126.4 RMB / m^2·year
Oil cost:	17.2 RMB / m^2·year
Total energy cost:	143.6 RMB / m^2·year

5.2 Energy Breakdown

The electricity using systems include lighting, equipment, chiller, pumps and cooling tower, fans, etc(See Figure 4).

The equipment part consumes the biggest amount of electricity, accounting for 45.5 %., which includes office equipment, 12 elevators (308kW totally) and an electrical water heater (12kW) on each floor. HVAC system consumes 22 % of total electricity, and lighting system accounts for 32.5 %.

Figure 5 shows the monthly electrical usage. The energy consumption of HVAC system is very correlative with the weather change. In summer, the chillers and cooling towers and pumps consume much more electricity than the other seasons. In winter, fuel boilers are used for the heating of the building ,which reduces the electrical consumption. On the contrary, the energy consumed by lighting and equipments are not concerned with the weather change, so it is relatively constant throughout the year.

6. ECMS EVALUATION

The final purpose of this paper is to provide a feasible energy conservation project for the mansion. So it is necessary to establish the energy saving target and to provide ECMs and to evaluate the effects of the ECMs.

6.1 ECMs

This paper proposes six ECMs[7]:

1) Optimizing operation of chillers and primary chilled water system;

2) Variable flow control of pump;

3) Enhance the efficiency of motor in fan coil system;

4) Replace one cooling tower;

5) Replace two cooling towers;

6) Reduce lighting density in office area.

The six ECMs are simulated based on the basic model(See Table 5).

6.2 Integrated ECM

The integrated ECM is the combination of the six ECMs. Table 6 shows the energy consumption and cost of the Integrated ECM by simulating.

The integrated model consumes less 6.1% energy than the basic model. And the first investment is 1,878,000 RMB. The integrated model can save energy cost 514,800 RMB each year. So the payback period is 3.6 years.

7. CONCLUSIONS

1) This paper simulated the building energy by using eQUEST. After three calibration (changing

Tab. 5 Energy conservation effect and economic analysis of six ECMs

Energy Saving Measure	Electricity Demand（kW）	Electricity Consumption（kWh/ m²）	Oil Consumption（MJ/ m²）	Energy Cost（RMB/ m²）	Reduced Cost（RMB/ m²）	Simple Payback Period （Year）
Basic Model	5476	157.4	166.1	143.6	-	-
Chillers' Optimizing	5479	157.4	165.9	143.5	0.1	4.3
Variable Flow Control	5423	155.9	167.6	142.5	1.1	1.9
Enhance Motor Efficiency	5357	156.1	166.5	142.6	1.0	3.8
Replace one cooling tower	5444	156.8	166.1	143.1	0.5	4.3
Replace two cooling towers	5431	156.5	166.1	142.8	0.7	6.4
Reduce lighting density	5178	147.3	179.3	136.8	6.8	3.1

weather data, refining schedule and lighting load) the basic model had the acceptable error from actual building. The maximal ERRmonth is -10.01％, the ERRyear is -2.37％. Based on the basic model, the paper analyzed the energy usage and energy consumption breakdown of the building.

2) The paper proposes six ECMs and simulated their effect and does simple economical analysis. The integrated ECMs that combines the six ECMs can save 6.1％ energy from the basic model. The payback period is 3.6 years.

3) The simulation tool is only the approximation to actual instance. It can not simulate random and unpredictable conditions. So it is necessary to study more reasonable calculating model and simulation method. Versed professional knowledge is very useful for energy simulation.

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Tab. 6 Energy and cost of basic model and integrated model

	Electricity Demand（kW）	Electricity Consumption (kWh/m²)	Oil Consumption (MJ/m²)	Total Energy (MJ/m²)	Total Energy Cost (RMB/ m²)	Reduced Cost (RMB/ m²)

Basic Model	5476	157.4	166.1	732.9	143.6	-
Integrated Model	5036	144.4	181.2	701.0	134.8	8.8

NOMENCLATURE

$$ERR_{month}(\%) = \left[\frac{(M-S)_{month}}{M_{month}}\right] \times 100\% \quad (1)$$

Where：M——measured energy use（kWh）

S——simulated energy use（kWh）

$$ERR_{year}(\%) = \sum_{year}\left[\frac{ERR_{month}}{N_{month}}\right] \quad (2)$$

Where：N——the number of utility bills in the year

The coefficient of variation of the root-mean-squared monthly errors:

$$RSME_{month} = \left\{\frac{\left[\sum_{month}(M-S)_{month}{}^2\right]}{N_{month}}\right\}^{1/2} \quad (3)$$

$$A_{month} = \left[\frac{\sum(M_{month})}{N_{month}}\right]$$

$$CV(RSME_{month})(\%) = \left[\frac{RSME_{month}}{A_{month}}\right] \times 100\%$$